Low lying, collective Proton-Neutron excitations as a tool to study Neutron-rich nuclei

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The lowest excitations of the known even-even nuclei, such as rotation or surface vibrations, are generally of isoscalar character. This means that the wave function is symmetric with respect to exchanging pairs of neutrons and protons. One consequence of this symmetry is the suppression of M1 transitions, which can only occur when at least two different angular momentum vectors with different g-factors are present in the configuration.

The lowest non-isoscalar states with at least one asymmetric proton and neutron pairs are called "Mixed Symmetry States" (MSS), as having "mixed" symmetric and antisymmetric components in the wave function. One fingerprint to identify these states are their strong M1 γ decays. The best studied examples of MSS are the "scissors mode" 1^+ states, which were established systematically around 3 MeV excitation energy in stable, deformed nuclei. Recently, the experimental evidence for another class of 2^+ MSS has been established in several cases of vibrational and transitional nuclei, in ^{134}Ba [1], ^{128}Xe [2] and ^{94}Mo [3,4]. Again, the fingerprint in the experiment is the observation of strong M1 decays. As I will explain below, the simple structure of these 2^+ MSS make them an ideal system to study the changes to nuclear structure as we approach very Neutron-abundant nuclei.

The structure of vibrational nuclei has with been categorized in terms of phonon excitations. The conventional phonon picture can be generalized to include deformed, transitional nuclei. In the so-called Q-phonon classification, the wave function of the low lying, collective states is produced by successive application of the quadrupole operator Q on the ground state. The E2-transition operator is proportional to Q, indicating that E2-transitions can only occur between states with ΔQ=1.

The first 2^+ state has the one Q-phonon wave function $|2^+\rangle = Q\ |0^+\rangle$, the two-Q-phonon states form a (non-degenerate) multiplet of $|4^+\rangle$, $|2^+\rangle = (Q\ Q)^{4,2}\ |0^+\rangle$, and so on. If, in a generalization, the Q operator is split into its proton and neutron contributions, two orthogonal, "one phonon" 2^+ states are generated, one isoscalar $|2^+_s\rangle = (Q_\pi+Q_\nu)\ |0^+\rangle$ and one isovector $|2^+_v\rangle = (Q_\pi-Q_\nu)\ |0^+\rangle$ state, forming a classic example of a two-state system. For calculations of the IBA-2 model, the lowest MSS can be shown to have exactly the $|2^+_v\rangle$ wave function structure.

If we think of the $|2^+_s>$ and $|2^+_v>$ states as the stationary solutions of the separate proton and neutron quadrupole excitations, it can be expected that the energy splitting of the two states decreases as neutrons grow less coupled to the core nucleus. At the same time, the measurement of M1 and E2 matrix elements allows for a quantitative determination of the mixing amplitudes. The ideal method to investigate these excitations is Coulomb excitation of radioactive ion beams, which will provide the tool to measure absolute γ-matrix elements. An ideal starting point for observing the behavior of 2^+ MSS for neutron-deficient nuclei would be to follow the N=52 and N=54 isotone chains to proton-deficient species.

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